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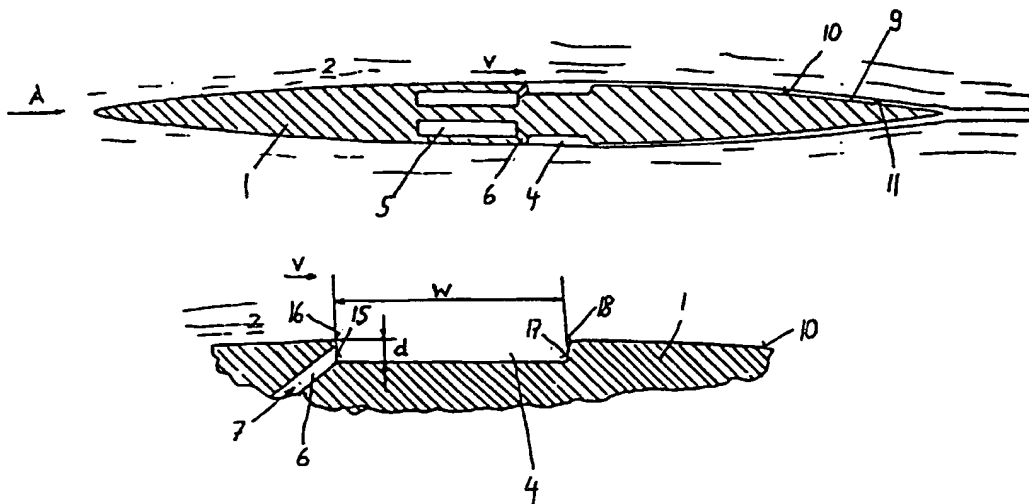
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ning of each regular issue of the PCT Gazette.

(54) Title: STREAMLINED BODY FOR IMMERSION IN A LIQUID AT HIGH RELATIVE SPEED



(57) Abstract: The invention is based on the objective of preventing cavitation on streamlined bodies which are immersed in a liquid (2) at high relative speed (v), permitting their use within wider speed ranges. To this purpose, in a transverse slot (4) a two-phase mixture of air and water is produced, which forms a two-phase mixture layer (9) downstream of the slot (4). The required air is supplied from an external source or precipitated from the air contained in the water in the transverse slot. Even without any air at all a water/water-vapour mixture layer is generated, which behaves in the manner of a two-phase mixture layer on account of the finely distributed vapour bubbles. The Reynold's number derived from the width of the slot (4) is greater than 20'000.

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Streamlined body for immersion in a liquid at high relative speed

The invention in question concerns a streamlined body according to the principle characterized in claim 1. The term streamlined body relates here in particular to hydrofoils, to rudders, to propeller blades or turbine blades etc. With such streamlined profiles, problems with cavitation occur at high speeds in fluids, e.g. in water. Cavitation occurs when the local pressure of the liquid on the streamlined body falls below the vapour pressure at the relevant temperature. Vapour bubbles are thereby formed, which implode downstream as the pressure increases, leading to cavitation corrosion.

In order to counteract this problem, supercavitating profiles have been proposed, which have a sharp leading edge, on which the flow separates. Behind the leading edge, a cavitation bubble forms on the suction side of the profile, which, in the case of supercavitating profiles, only collapses behind the trailing edge. Cavitation damage is thereby avoided. These supercavitating profiles have relatively high drag coefficients, however, and can only be employed in limited ranges of angles of attack and speed.

in the US patent A 3,896,752 a subcavitating hydrofoil profile is described with controlled airfeed on the pressure side as well as on the suction side of the profile. The air is supplied via ducts to narrow holes or slots, which emerge at the profile surface. Downstream of these holes or slots, a veil of air is formed adhering to the profile between the profile and the free-flowing water stream.

In the WO 99/62761 another concept for supercavitating profiles is proposed, in which, a two-phase mixture of infed air and water is formed in a slot perpendicular to the direction of flow, which due the low speed of sound in the mixture, leaves the slot at supersonic speed. This has the advantage that pressure changes along this mixture cannot propagate upstream. This WO 99/62761 is declared as integral part of the present application.

The present invention is based on the objective of developing such a streamlined body so that a two-phase mixing layer can be maintained reliably over a wider range of speeds and pressure gradients. This task is solved by means of the combined features of the claims.

During extensive towing tests it was found that the reliable formation of an intensive mixture of air and water depends on the width of the slot measured in the direction of flow. The Reynold's number derived from this width and the speed of flow of the liquid must exceed 20'000. The slot does not need to be deep, but should be at least equal to the thickness of the boundary layer of the water in the zone of the slot. The required necessary width of the slot is thus independent of the length of the profile, measured in the direction of flow, whereas the required slot depth is dependent on this length and on the position of the slot in the profile longitudinal direction.

Surprisingly it has been discovered that the mixing layer downstream of the slot even forms without air supply to the slot. For at the breaking edge of the upstream flank of the slot, the air dissolved in the water segregates in the finest of bubbles, which initiates the intensive mixing layer. Even any vapour bubbles that may form are so fine that they do not momentarily collapse as the pressure rises, but remain in the gaseous state, which likewise increases the compressibility of the two-phase mixture layer.

In liquid droplets the vaporization is all the more prevented by the surface tension, the smaller the droplet. For small vapour bubbles in a liquid, the effect is the reverse. The smaller the vapour bubble, the more the evaporation in the vapour bubble is backed up by the surface tension. Small vapour bubbles therefore collapse much less easily than large ones.

In the following a realization of the invention is explained with reference to the drawing. This shows:

- Figure 1 a streamlined body according to the invention, in the form of a hydrofoil profile, and
Figure 2 an enlarged detail.

The invention is explained in the following with respect to a hydrodynamic foil for hydrofoils or hybrid boats. It is also applicable, however, for other streamlined bodies, e.g. for struts, rudders, propeller blades or turbine blades, that are subjected to high flow speeds, also well above 25 m/sec.

Figure 2 depicts schematically a detail of a hydrofoil profile 1 in flowing water 2 assuming the local speed v of the water flow 2 in the direction of flow A to exceed 25 m/sec. This speed e.g. would exceed the lower value of the speed of sound in an air-water mixture and results in supersonic flow of the mixing layer. The hydrofoil is provided with a slot 4 running perpendicularly to the direction of flow A, i.e. basically in the hydrofoil longitudinal direction, which can be supplied with air via a channel 5 and transverse holes 6. The width of the slot 4 measured in the direction of flow A is of such dimension that the Reynold's number derived from this width w , the speed of flow v and the kinematic viscosity ν of the liquid, $Re = v w / \nu$ is at least 20'000. The depth of the slot 4 is at least equal to the thickness of the boundary layer of the liquid 2 immediately upstream of the slot 4. The upstream flank 15 of the slot 4 meets the surface 10 of the profile 1 as a sharp edge. The downstream flank 17 merges with the surface 10 with a radiussed edge 18. Both flanks 15, 17 are relatively steep. As seen from Figure 2, the slot 4 is considerably wider than deep. The ratio of width w to depth d is at least 4:1; in the example depicted about 10:1.

The two-phase mixture escapes downstream of the slot 4 as a two-phase mixing layer 9 between the surface 10 of the profile 1 and the surface 11 of the flowing water 2 facing the profile 1. The mixing layer 9 flows approximately at the speed v of the water 2, so that from a flowspeed v of about 25 m/sec. upwards supersonic speed prevails. The supply rate of the air 7 can be adjustable.

It has been revealed that with the dimensions stated, no gas supply, e.g. air, is required in order to form the two-phase mixture in the slot 4, but a controlled air supply is useful for regulating the lift of a hydrofoil. In other cases of application, e.g. propellers and turbine blades, however, this is not necessary. There are hence many cases where by simple means, such as the milling of a simple slot of the appropriate width of e.g. 10 mm and appropriate depth, the dreaded cavitation damage can be avoided.

In contrast to the proposal according to WO 99/62761 the two-phase mixture is not generated in a vortex, but in the turbulent flow in slot 4.

Instead of pure air 7, the slot 4 can also be supplied with a prepared air/water mixture via the channel 5 and the holes 6, whereby the supply rate and/or the void ratio of the mixture can be adjustable.

Figure 1 depicts schematically a hydrofoil profile 1 drawn symmetrically. It is provided on both sides with slots 4 roughly at the point of maximum profile thickness, with appropriate air supply channels 5 and holes 6. By varying the ratio of the air or mixture quantity to the opposing slots 4, the thicknesses of the mixing layer 9 downstream of the slots 4 can be influenced, and with it the circulation around the profile 1 and the lift of profile 1.

With supersonic speed for the mixture layer, a higher static downstream pressure cannot propagate upstream, and a greater thickness of the two-phase mixture layer 9 does not cause separation; no cavitation can occur. Several slots 4 can also be arranged one behind the other. The mixture layer 9 can thereby be built up in stages.

To support cavitation avoidance at speeds below sonic speed of the mixture layer, injection of air will cause appropriate thickness of this layer.

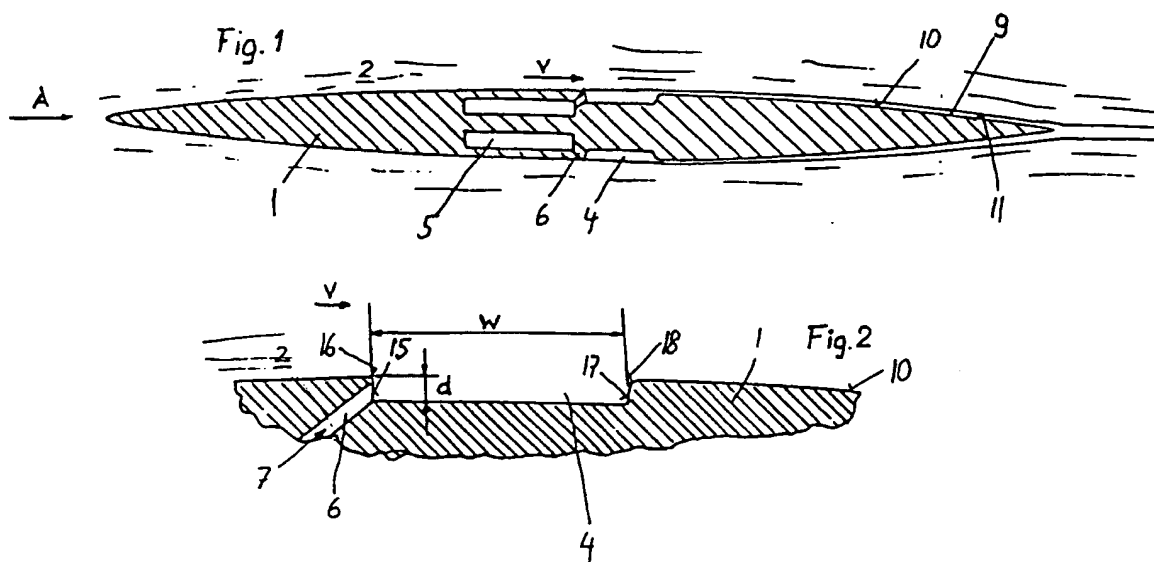
Claims to patent

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1. Streamlined body immersed in a liquid at high relative speed, embodying a slot (4) open towards the free-flowing stream, which slot runs largely perpendicular to the direction of flow (A) and in which a two-phase mixture of liquid (2) and gas (7) is formed, characterized such that the width (w) of the slot (4) open towards the free-flowing stream, as measured in the direction of flow (A), is of such dimension that the Reynold's number derived from this width (w) and the speed of flow (v) and the kinematic viscosity ν of the liquid (2) is at least 20'000.
2. Streamlined body according to claim 1, in which the depth (d) of the slot (4) measured perpendicularly to the direction of flow (A) is greater than the thickness of the boundary layer of the liquid stream immediately upstream of the slot.
3. Streamlined body according to claim 1 or 2, in which the upstream flank (15) of the slot (4) meets the outer profile of the streamlined body as a sharp edge.
4. Streamlined body according to one of the claims 1 to 3, in which the downstream flank (17) of the slot (4) merges with the outer profile of the streamlined body as a radiussed edge.
5. Streamlined body according to one of the claims 1 to 4, in which it is additionally provided with a channel (5) for the controlled supply of a gas or a gas/liquid emulsion to the slot. (4)
6. Streamlined body according to one of the claims 1 to 5, in which it is provided with several slots (4) one behind the other in the direction of flow for the build-up of the two-phase mixture layer in stages.

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Fig. 1 and 2



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B63B1/28 B63H1/18

According to International Patent Classification (IPC) or to both national classification and IPC.

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 99 62761 A (SUPRAMAR AG ; ROCHE ULRICH (CH)) 9 December 1999 (1999-12-09) the whole document	1,2
Y	FR 2 005 751 A (LIPS NV) 19 December 1969 (1969-12-19) figure 2	1,2
A	US 3 896 752 A (VON SCHERTEL HANNS) 29 July 1975 (1975-07-29) abstract; figures 1-3	1
A	EP 0 264 326 A (FRANCE ETAT) 20 April 1988 (1988-04-20) the whole document	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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